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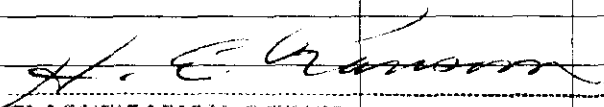
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STATUS OF THE GROUND WATER BENEATH HANFORD REACTOR AREAS

JANUARY, 1962 TO JANUARY, 1963

By

Donald J. Brown

Chemical Effluents Technology  
CHEMICAL LABORATORY

April, 1963

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FOR THE ATOMIC ENERGY COMM.

Prepared for the Atomic Energy Commission by the  
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INTRODUCTION

Several years after operations started in each of the Hanford reactor areas, the temperature of the ground water beneath those sites increased noticeably. It was found that the temperature increase in most cases was caused by thermally hot reactor effluent cooling water percolating downward into the ground through cracks and joints in the bottom of the 107 retention basin structures and leaking pipe lines carrying the water to these basins. As a result of this leakage, ground-water mounds were formed beneath the retention basins which greatly increased the hydraulic gradients between the basins and the Columbia River. The gradients thus formed were sufficient to produce river-bank thermal springs in the proximity of the retention basins at each reactor area.

In 1962, a study was made to determine the effects that thermally hot ground water might have on reactor operations. A temperature probe was developed and used to obtain temperature-profile data on the ground water beneath each of the reactor sites. These data were used to calculate temperature distributions in the ground water. Knowledge of the temperature distributions and the geologic and hydrologic characteristics at each site permitted the determination of the heat flow via the ground water into the Columbia River. Isotopic analyses of well and spring waters were used to confirm the present hydrologic concepts regarding the direction and rate of ground-water movement beneath the areas.

This paper presents an interpretation of the temperature data obtained from this study together with perspective sketches of the water table beneath each of the reactor areas. Superimposed on the water table in these sketches are the latest temperature distribution patterns. Also presented are estimates of the heat flow into the Columbia River via the ground water at each of the reactor sites, and an estimate of the total quantity of heat contributed by the ground water to the Columbia River as it flows through the course of the Hanford Project.

SUMMARY AND CONCLUSIONS

The temperature of the influent cooling water pumped from the forebay at the 100-B Area, and to a lesser degree at the 100-F and 100-H Areas, is raised by the flow of thermally hot ground water into the river at the forebay sites. The only measurable difference, as much as several degrees Centigrade, occurs at the 100-B Area.

Channeling of the effluent cooling water from beneath the retention basins to the river, with the gradual removal of the fine-grained sediments from the formations underlying each site, may eventually cause some slumping of the ground.

Based on conditions when the low flow of the Columbia River would show the greatest effect, calculations indicated that all of the project ground water, including the effluent cooling water leaking from the retention basins, would increase the overall temperature of the Columbia River by less than 0.2 C. The river temperature increase attributable solely to thermally warm water flowing from beneath the reactor areas is estimated to be on the order of 0.05 C.

Although some previous evidence pointed to the possibility of a natural source of thermally hot ground water beneath the 100-B Area, this was contraindicated by recent temperature logging data. Temperature profiles indicate the only sources of thermally hot water in the region of the reactor areas are reactor effluent cooling water leakage and local discharge.

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## DISCUSSION

### Temperature Logging System

A well water temperature logging system was designed and fabricated at Hanford to measure and record well water temperatures at depth<sup>(1)</sup>. This system consists of a thermistor sensing probe, electrical wire line, measuring circuitry, power-driven cable reel and a recorder. The temperature range of the equipment is from 3 to 98 C. The probe is designed to operate to a depth of 800 feet below ground surface and under water pressures up to 250 psi. The sensitivity of the system is 0.2 C, with an accuracy of 0.5 C. It has a response of 2 degrees per second and can continuously record temperature with depth. No significant problems were encountered with either the reliability or the maintenance of this equipment during the monthly logging of more than 100 wells in 1962.

### Geothermal Gradient

Below a mantle of sediments approximately 50 feet thick the temperature usually increases with depth at a fairly constant rate depending on the type of material present. In the unconsolidated and semi-consolidated sediments which underly the Hanford Project, the gradient is approximately one degree Centigrade for 120 to 140 feet of depth. Beneath these sediments, in the basalt bedrock, the gradient increases to one degree Centigrade for 90 to 100 feet of depth.

The rise of temperature with depth is attributable to the radioactive heat generation within the rocks themselves and the subsequent outward flow of this heat by conduction. The heat flux through the basalt within the Pasco Basin is estimated to be in the range of 30 to 60 calories per year per square centimeter<sup>(2)</sup>. On the basis of this estimate the possibility of the basalt heating the ground water to a significant degree, even with residence times up to 100 years, appears remote.

The only natural-occurring temperature irregularities noted on the Hanford Project are those resulting from variations in the topography. Seasonal temperature changes affect the temperature of the ground water wherever the water table is within 5 to 15 feet of the ground surface. In areas where a thick covering of sediments occurs above the water table, ground water temperatures are not influenced by seasonal variations.

There are two general regions in the vicinity of the reactor areas where the ground water is sufficiently close to the ground surface to be affected by the seasonal temperature changes. One region is west of 100-F Area and the other is southwest of 100-H Area. During the year 1962, temperature changes of from 3 to 5 C were noted in wells in these regions.

### 100-B Area

Of the five reactor areas now operating at Hanford, the 100-B Area is located farthest upstream on the Columbia River (see Figure 1). This Area encompasses approximately one square mile. It is situated over a synclinal trough in the basalt bedrock and is underlain by over 650 feet of unconsolidated sediments<sup>(3)</sup>. The depth to the water table ranges from 30 to 80 feet and the thickness of the free ground-water aquifer, the zone through which ground water moves into the Columbia River, is approximately 250 feet.

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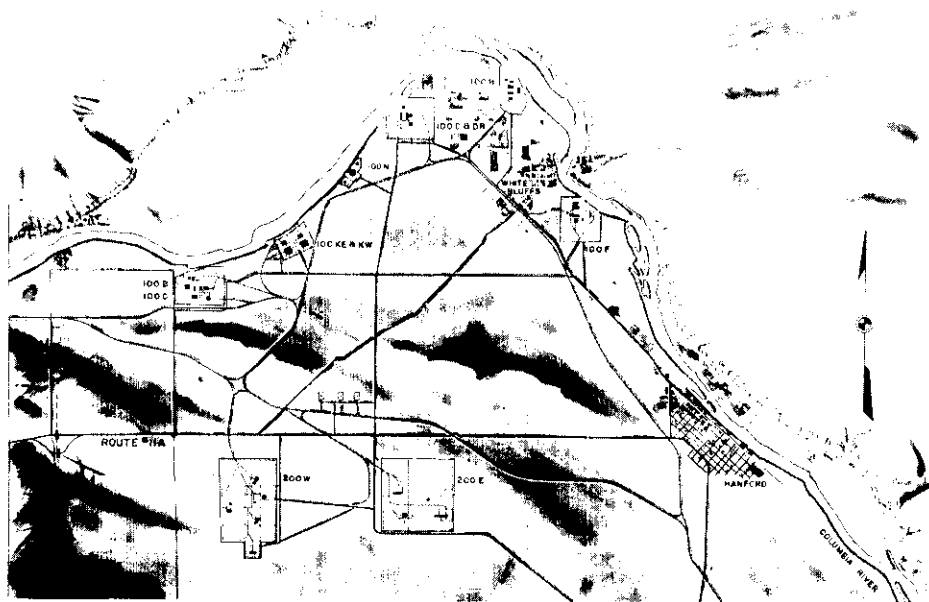


FIGURE 1.  
Well Location Map

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-6-

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Reactor effluent cooling water enters the ground at several different locations within the 100-B Area. The most significant locations are adjacent to leaking joints along the effluent pipe lines which run from the reactor building to the retention basins. Another entry site, when in use, is the 107-B retention basin. The effluent cooling water percolates into the ground beneath this basin through cracks formed in the bottom and sides of the structure. At the present time, this basin is used intermittently. Because of the relatively large volume of effluent cooling water which has entered the ground beneath these sites, ground water mounds have formed beneath them. Figure 2 is a perspective drawing showing the outline of 100-B Area, the location of the effluent pipe line, and the retention basins. The relief on the present water table was constructed from well tapping results. The two mounds are shown rising up beneath the effluent pipe line and the retention basin. The actual elevation of the top of the highest mound is approximately 420 feet above mean sea level. Because of the vertical scale used in this sketch, the top of the mounds were not shown. The mound beneath the effluent pipe line is divided, probably as a result of recent repair work in that section of the line. It is estimated that approximately 1.5 million cubic feet of effluent cooling water per day enter the ground from these two source areas and flow into the Columbia River.

Superimposed on the water table relief sketch in Figure 2 is the temperature distribution pattern. This shows a zone beneath the effluent pipe line where the temperature is 80 C. The temperature drops to 40 C at the river level around the forebay of the pump house. The greatest depth below the water table to which thermally hot water could be detected was 250 feet. This substantiates the geologic data which show the sediments at this depth are relatively impermeable and represent the bottom of the free ground-water aquifer. A relatively sharp temperature decrease also occurs at a depth of 100 feet below the water table. The sediments below this depth are predominantly sands and gravels having an average temperature of 18 C. Above this depth the sediments contain silt combined with sand and gravel. The temperature of the ground water in the latter zone averages between 30 and 40 C.

Isotopic analyses of well and spring waters for Cr<sup>51</sup> were used to calculate the average rate of movement of the ground water from the points of recharge. These travel rates are also shown on the perspective drawing in Figure 2. The fastest travel rate was in a westward direction from the retention basins which accounts for the higher temperatures in and about the pump house forebay.

Thermal springs seep out of the ground along the river bank upstream and downstream from the pump house for a total distance of about one mile. The most prominent of these is located 1000 feet west of the pump house. The temperature of the spring water at that site is 45 C. Several springs, and by far the largest in volume, occur at the edge of the forebay where the hot water can be seen welling-up to create eddies at the water surface. Past measurements have shown that this spring water has at times reached a temperature of 70 C; temperatures of 45 and 50 C were recorded over the past year.

The preferential direction of warm water movement, towards the pump house forebay, is probably attributable to the drawdown of adjacent ground water by the influent pumps and the quite permeable channels created by the progressive washing-out of fine sediments. Temperature measurements and isotopic analyses of the influent coolant confirm that this is the preferential path for warm water returning to the river.

Indirectly the movement of thermally hot effluent cooling water through the sediments at 100-B Area may create problems relative to the stability of structures within the area in that the washing-out of fine sediments may cause slumping to occur.

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- 7 -

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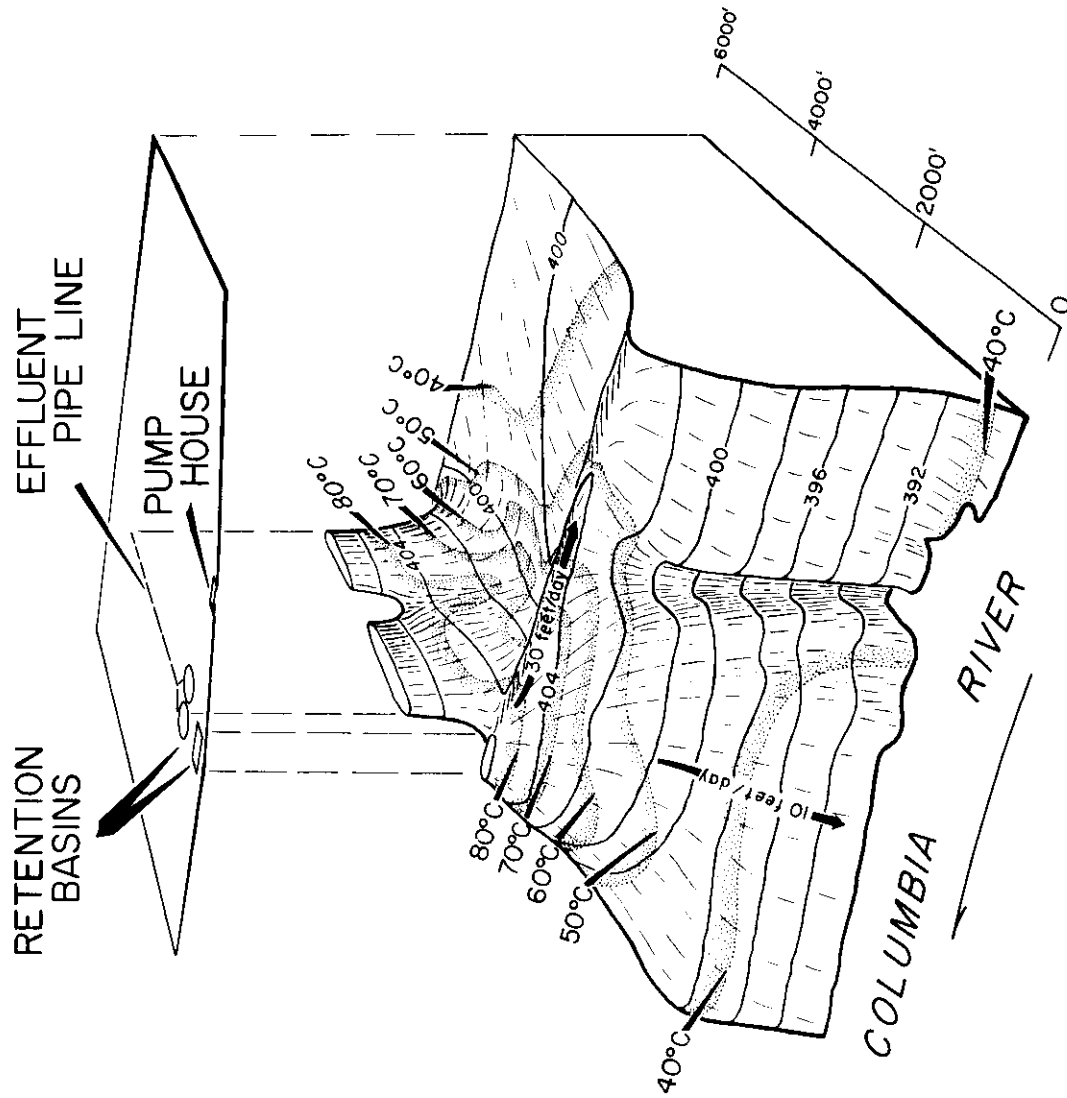


FIGURE 2.  
Perspective Drawing Of The Water Table Underlying The 100-B Area

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### 100-K Area

The 100-K Area, the first reactor area downstream from 100-B Area, encompasses approximately one square mile. The only major source of thermally hot water to ground here is an unlined trench (ditch) located just east of the 100-K Area fence. This ditch is 4,000 feet long and, until 1963, received approximately one to five billion gallons of effluent cooling water a year. Most of this water came through leaking valves in the piping system at the retention basins. Recently, however, much of this effluent cooling water was rerouted to the river directly and the discharge rate is now estimated to be only five-hundred million gallons per year into the ditch. Figure 3 is a perspective drawing showing the location of the ditch east of 100-K Area and the ground-water mound which has formed beneath it. The elevation of the top of the mound is approximately 420 feet above mean sea level. The maximum temperature occurs beneath the western end of the ditch, within the zone delineated by the 40 C isotherm. The temperature gradually decreases to about 19 C where the effluent seeps out of the ground at the edge of the river. Springs which occur nearer the ditch have higher temperatures. The temperature increases rapidly with depth near the river to 40 C and then drops off to background temperatures of 17-18 C at about 50 feet.

The estimated average ground water velocity between the ditch and the river, based on results from isotopic analyses, is 10 feet per day. On the basis of geological information, the velocity toward the west (beneath the eastern edge of the 100-K Area) is on the order of several inches per day. Geological investigations show a zone of cemented sand and gravel extending along the eastern margin of the Area which greatly restricts the movement of ground water in that region. In the western portion of the 100-K Area, however, it appears that there is a more permeable zone as evidenced by the ground-water contours shown in the perspective sketch of the area. These contours suggest a shallow ground-water gradient with velocities in the range of 30-40 feet per day.

The free ground-water aquifer through which effluent cooling water enters the Columbia River is approximately 60 feet thick and is predominantly made up of sand, silt and gravel. It is estimated that 500,000 cubic feet of effluent cooling water with an average temperature of 25 C entered the Columbia River through this aquifer daily when the flow into this ditch was at its maximum. The temperature effect on the Columbia River from this relatively small volume of ground water is negligible. Any problems of ground slumping caused by channeling of the ground water from the ditch to the river will be insignificant since no structures or roads exist in this area.

The general direction of movement of this thermally hot ground water appears to be toward the river to the north, and inland to the east and southeast. The 100-N Area is located less than one mile away from this ditch to the northeast. It is believed that this thermally hot ground water will eventually move to the 100-N site; however, it is not possible at this time to determine what effects this hot ground water might have on the operations in that area.

### 100-D Area

The 100-D Area, located downstream of 100-K Area (Figure 1), covers an area of one square mile. There are two retention basins located in the northern part of the area from which significant quantities of effluent cooling water escape into the ground. The relative positions of these two basins with respect to the area and

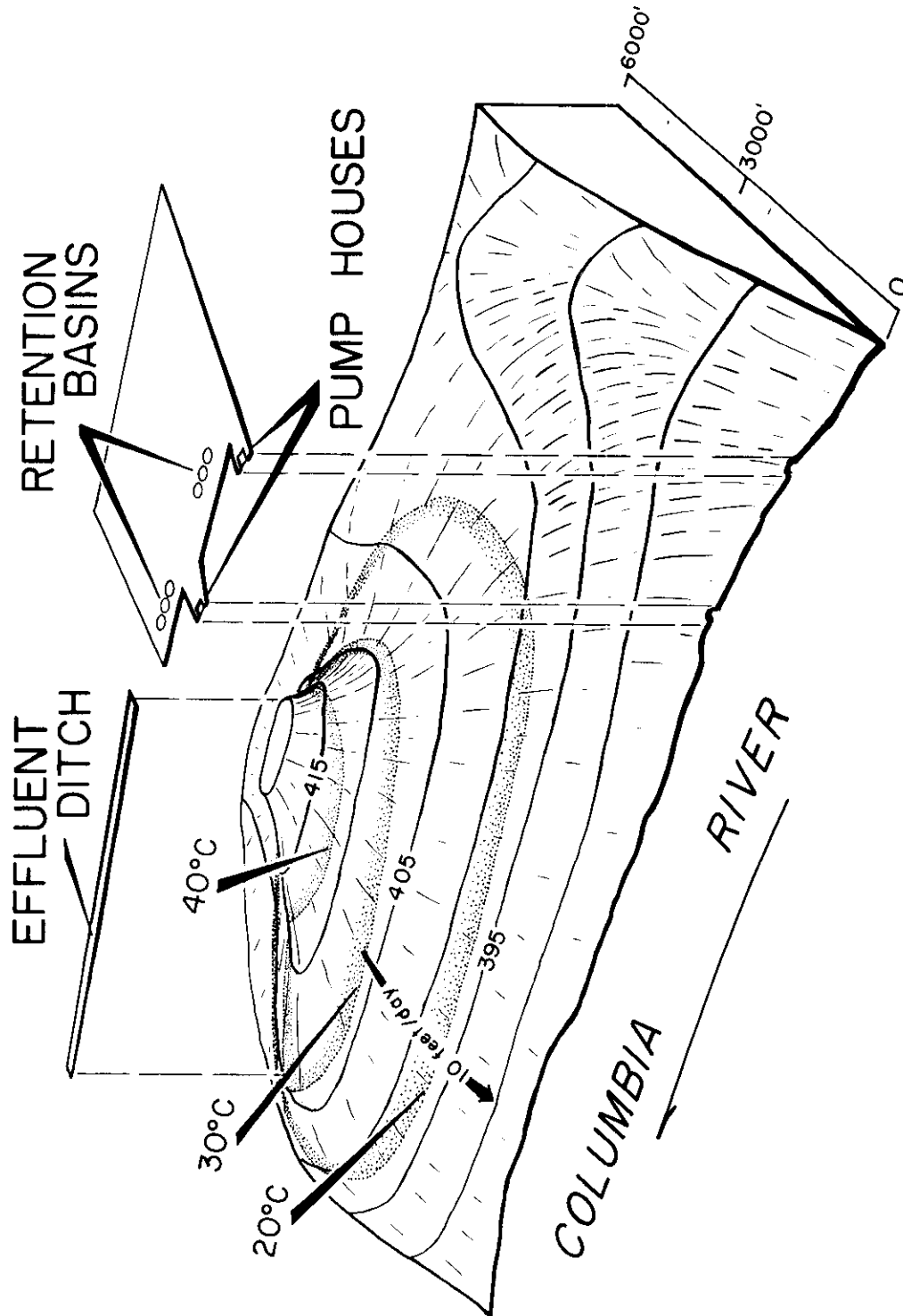


FIGURE 3.  
Perspective Drawing Of The Water Table Underlying The 100-K Area

the ground-water mounds formed beneath them are shown in Figure 4. The actual elevation of the top of the mound is approximately 410 feet above mean sea level; however, in this sketch the mound was cut off at the 400 foot contour. In this sketch the movement of the ground water is shown to have a preferred direction of movement towards 100-H Area to the northeast. The permeability of the sediments in this region and the gradient created by the ground-water mound beneath 100-D result in relatively high flow rates. Calculations based on isotopic analyses of well water samples place the average rate at approximately 30 feet per day. From the apex of the mound in a direction toward the Columbia River the velocity drops off to only 10 feet per day. There appears to be very little movement towards the southwest or southeast in this area.

The temperature distribution pattern shown in Figure 4 indicates that at one location the temperature of the ground water entering the river exceeds 50 C. The maximum temperature recorded at this point was 54 C. Thermal springs occur along 2000 feet of riverbank downstream from the two outfall flumes located in the northwestern corner of 100-D Area. The ground-water aquifer carrying water into the river is estimated to average 40 feet thick in the region where these springs occur. The rate at which ground water enters the river through this aquifer is approximately 200,000 cubic feet per day. At an average temperature of 35-40 C, this would result in a temperature rise of about 0.003 C, assuming the effluent is mixed uniformly with the river water during a minimum flow and minimum temperature period.

One effect that this leaking effluent cooling water has had on structures at 100-D Area was the recent slumping which occurred beneath the north wall of the 107-D retention basin<sup>(4)</sup>. This was caused by the washing-out and reworking of the fine material from the underlying sediments. It is unlikely that any of this thermally hot ground water enters the 100-D forebay. However, the slightly higher than background temperatures measured a few hundred yards upstream of the 100-H forebay indicate that some of the effluent cooling water from 100-D Area is entering the forebay at 100-H Area.

#### 100-H Area

The relative position of 100-H Area with respect to the other reactor areas is shown in Figure 1. This Area encompasses approximately three-quarters of a square mile. There is only one retention basin in this area as shown in Figure 4. The height of the ground-water mound beneath this basin is approximately 405 feet above mean sea level. The thermally hot reactor effluent cooling water which infiltrates into the ground water beneath the basin has raised the background temperature at this site from 16-17 C to over 70 C. There appears to be very little change in ground-water temperature from the basin site to the riverbank. Thermal springs at the edge of the river range up to 74 C. Although the free ground-water aquifer is estimated to be only 40 feet thick, above background temperatures were measured to a depth of 200 feet. To the north, west and south the temperature of the ground water decreases rapidly to background values. The thermal springs which crop out along the riverbank can be traced for a distance of 3000 feet.

The extent to which thermally hot ground water raises the temperature of the Columbia River during minimum flow and temperature was calculated to be approximately 0.007 C. This assumes that ground water flows into the river at a rate of 500,000 cubic feet per day and an average temperature of 50 C.

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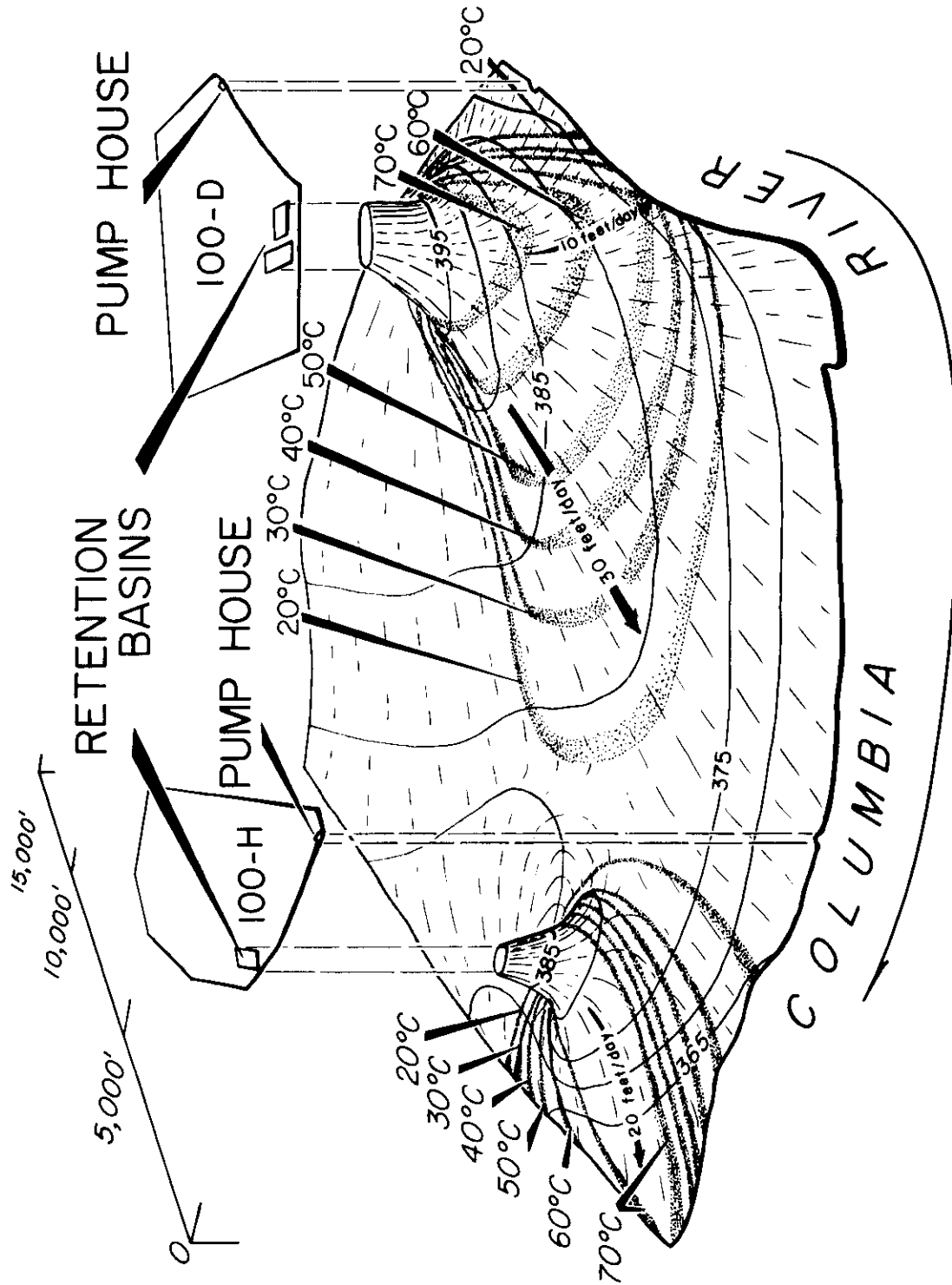


FIGURE 4.  
Perspective Drawing Of The Water Table Underlying The 100-D and 100-H Areas

KEGGE HIGHLAND WAVER

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-12-

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No apparent effects from effluent leakage are evident in this area; however, slumping on the eastern side of the area may eventually occur, depending on the rate at which the fines are removed.

#### 100-F Area

The farthest reactor area downstream is the 100-F Area. This area originally encompassed one square mile; however, the fence line was changed recently and the area was reduced to one-fourth square mile. Because of the familiarity of plant personnel and others with the original outline of the area, it was selected for the perspective sketch shown in Figure 5. The ground-water mound beneath the retention basin was created by leakage of the effluent cooling water into the ground through cracks and joints in the bottom of the basin. The actual height of this mound, approximately 385 feet above mean sea level, is shown in this sketch. The temperature distribution pattern, shown superimposed on the relief of the water table, is quite similar to that of the 100-H Area (Figure 4). The temperature of the ground water beneath the 107-F basin is greater than 70 C. The temperature of the springs also exceeds 70 C over much of the 6000 feet of riverbank along which they are exposed. Isotopic analyses of the spring water showed average ground water velocities toward the river to be 28 feet per day. This same condition does not exist inland from the basin. Geological investigations of the formations beneath the 100-F Area and the regions directly to the west, north and south showed evidence of a buried channel of the Columbia River in this locale. Separating the ground water in this channel and the ground water in the 100-F mound is a natural levee of Ringold sediments composed primarily of silts and clays. During the late spring and early summer months ground-water recharge by the Columbia River moves through this buried channel toward the south. In the periods of low river flow, the ground water in the channel drains back into the river. There is no evidence to indicate that thermally hot water from the retention basin is getting into this channel. The sketch in Figure 5 shows some indication of a channel inland from the mound beneath the basin.

It is estimated that slightly over one million cubic feet of thermally hot ground water enters the Columbia River daily at 100-F Area. The average temperature of this water was calculated to be near 60 C. This flow would raise the river temperature 0.014 C during the period of low flow and temperature. Some of the thermally hot ground water enters the forebay of the pump house, but no effect on the over-all heating of the influent cooling water could be measured. It is unlikely that the temperature of the influent cooling water is increased more than a fraction of a degree Centigrade. Slumping on the east side of this area may occur in the future if basin leakage continues to percolate through the sediments.

#### Temperature And Flow Contributions Of The Ground Water To The Columbia River

The estimated values for the inflow of effluent cooling water leakage into the Columbia River at each of the reactor areas together with the average temperatures were used to evaluate the heat contributed to the river by these sources. Also, similar evaluations were made for ground water entering the river from both banks between Vernita and Richland excluding the reactor areas. The results are summarized in the following table.

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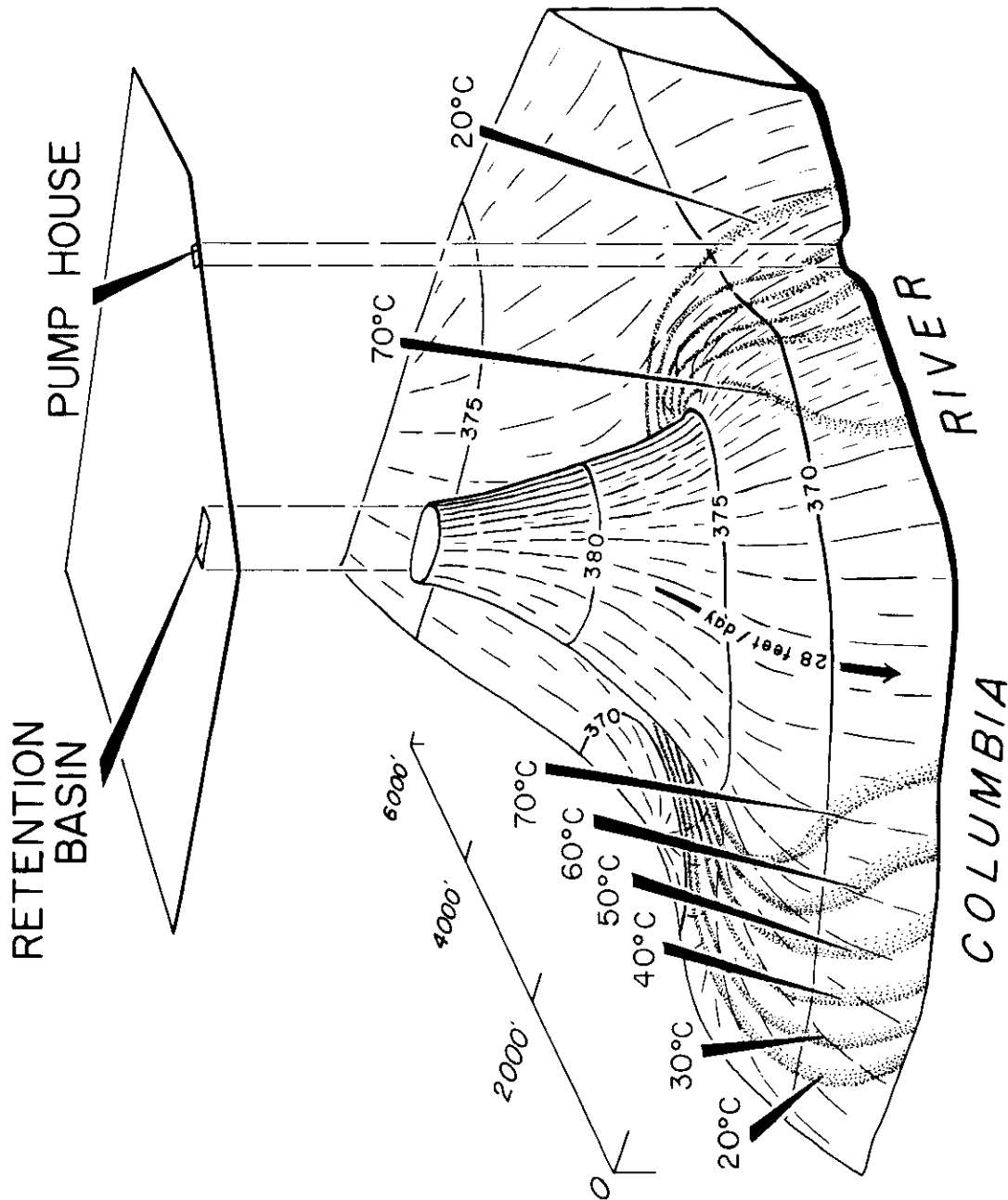


FIGURE 5.  
Perspective Drawing Of The Water Table Underlying The 100-F Area

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-14-

TABLE I

GROUND WATER TEMPERATURE CONTRIBUTIONS TO THE COLUMBIA RIVER  
(River flow at 4,320,000,000 cubic feet per day and 3 C)

<u>Area</u>	<u>Flow Rate</u> (cubic feet/day)	<u>Average Temperature</u> (°C)	<u>Increase</u> <u>in Temperature</u> (°C)
100-B	1,500,000	40	0.014
100-K	500,000	25	0.005
100-D	200,000	40	0.003
100-H	500,000	50	0.007
100-F	1,100,000	60	0.014
South and West Riverbanks	17,300,000	17	0.048
North and East Riverbanks	21,100,000	17	0.068
	<u>42,200,000</u>		<u>0.159</u>

The calculation of flow from both banks of the river was based on a free ground-water aquifer 40 feet thick and an average flow rate of 10 feet per day.

#### Natural Thermal Springs

In 1953, a well constructed in 100-B Area penetrated the uppermost basalt flow. Beneath this flow an interbed of volcanic tuff and white quartz sand was encountered. When the well penetrated into the interbed, thermally hot water (55°C), rose inside the well casing to within 31 feet of ground surface. It was presumed at that time that the warm water came from the interbed, and that the heat was generated from friction along a fault zone underlying the area. However, careful examination of the well with the temperature probe revealed no abnormal temperature increase with depth other than that near the surface of the water table created by effluent cooling water. Based on this more recent evidence, hot water measured in the well in 1953 was effluent cooling water leakage.

Ground-water temperature profiles obtained in 274 wells drilled on the Hanford Project revealed no abnormal thermal gradients which would suggest the occurrence of natural thermal springs in this area. Irregularities do occur in some regions on the Project, but these are attributable to topographic effects, seasonal variations in temperature, and local waste disposal operations.

#### ACKNOWLEDGEMENT

The assistance of V. L. McGhan and R. E. Brown in collecting and preparing the data used in this report is greatly appreciated.

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